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URBANA

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VISCOSITY STUDIES OF SYSTEM
 $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$: III, 35%, 45%, and 50% SiO_2

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ABSTRACT

In this continuation of previous papers on viscosity in the system $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$, data are presented for melts containing 35% SiO_2 , 45% SiO_2 , and 50% SiO_2 with varying percentages of the other three oxides that make up the system.

INTRODUCTION

IN PREVIOUS papers data have been presented showing the manner in which viscosity varies with temperature and with composition in those parts of the system under consideration which contain 40% SiO_2 ¹ and which contain no MgO .² The data here presented were obtained by the methods and with the apparatus described in the previous papers and are treated in a similar manner.

PREPARATION OF SAMPLES AND DISCUSSION OF ERRORS

In experimental work with glass where small samples are prepared from batch, it is customary to melt the samples, grind the resulting glass, and remelt it one or several times to make certain of the uniformity of the sample. In the present investigation the amount of time that would be consumed by this procedure is so great that it was decided to use other means to minimize possible error from nonuniformity of the sample. The batch materials (all -200 mesh) were mixed in a tumbling jar, put through a 20-mesh screen to break up any lumps, and then put into the tumbling jar for a further

period. The briquetted material was then melted in the crucible in which measurements were to be made. To test whether errors due to nonuniformity of samples were being made, a series of five samples was prepared in the usual manner, but in larger quantity. All these samples contained 65% SiO_2 and 5% MgO . The amounts of Al_2O_3 and CaO varied from 5 to 25% in the five samples. The reason for choosing these compositions is that it was considered that since the high-silica melts are usually more viscous, diffusion would be slow in them and the effects of nonuniformity of composition would be more likely to show up. One part of each of these samples was melted and the viscosity measured according to the regular procedure. A second part was melted, allowed to cool, ground through a 50-mesh screen, and remelted. The viscosity was then measured and the results compared with those from the first part.

The comparison indicated that the crushing and remelting on the average reduced the viscosity slightly. One sample was not changed appreciably. The average reduction in viscosity was about the same as the probable error of the measurements (i.e., about 4%). On any one sample it could not be said with certainty that the lowering in viscosity was due to the crushing and remelting since the difference was of the same order of magnitude as the probable error, but the fact

¹J. S. Machin and D. L. Hanna, "Viscosity Studies of System $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$: I, 40% SiO_2 ," *J. Am. Ceram. Soc.*, 28 [11] 310-16 (1945); *Illinois State Geol. Survey Rept. Investigations*, No. 111 (1945).

²J. S. Machin and T. B. Yee, "Viscosity Studies of System $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$: II, $\text{CaO-Al}_2\text{O}_3\text{-SiO}_2$," *J. Am. Ceram. Soc.* 31 [7] 200-204 (1948); *Illinois State Geol. Survey Rept. Investigations*, No. 137 (1948).

TABLE I.—VISCOSITY DATA FOR THE SYSTEM
LIME-MAGNESIA-ALUMINA-SILICA ($\text{SiO}_2=35\%$)

| Melt No. | Composition (Wt. %) | | | Viscosity (poises) | | | | |
|-------------|-------------------------|-----|-----|--------------------|------|------|------|------|
| | Al_2O_3 | CaO | MgO | (°C.) | | | | |
| | | | | 1500 | 1450 | 1400 | 1350 | 1300 |
| 265 | 10 | 45 | 10 | 2.3 | | | | |
| 266 | 10 | 40 | 15 | 2.1 | | | | |
| 262 | 15 | 45 | 5 | 3.0 | 4.6 | 7.0 | | |
| 254 | 15 | 40 | 10 | 2.7 | 3.9 | 6.0 | | |
| 263 | 15 | 35 | 15 | 2.6 | 3.6 | 5.3 | 8.3 | |
| 18 | 20 | 40 | 5 | 4.8 | 7.2 | 11.4 | | |
| 255 | 20 | 35 | 10 | 4.1 | 5.4 | 8.2 | 13.7 | |
| 19 | 20 | 30 | 15 | 3.9 | 5.7 | 8.9 | | |
| 141 | 25 | 40 | 0 | 7.5 | 11.8 | 19.9 | | |
| 256 | 25 | 35 | 5 | 6.5 | 9.4 | 15.3 | 25.5 | |
| 257 | 25 | 30 | 10 | 5.6 | 8.1 | 13.0 | 21.5 | 39.8 |
| 144 | 30 | 35 | 0 | 11.6 | 18.9 | 31.7 | | |
| 37 | 30 | 30 | 5 | 11.2 | 16.6 | 26.0 | 48.2 | 92.4 |
| 259 | 30 | 25 | 10 | 9.2 | 16.7 | 31.4 | | |
| 146 | 35 | 30 | 0 | 19.0 | 31.4 | 54.8 | 109 | 248 |

that the changes were all in the same direction indicates that the results would have been slightly better if all samples had been crushed and remelted.

For all the data presented in this series of papers the viscosity values are least reliable for those compositions that might develop new phases at the temperature of the experiment. The reasons for this are as follows: (1) It is possible that non-uniformity of the melt due to the formation of crystals which are not detected may result in misleading data. (2) When the sample is cooled after the preliminary melting and fining, a clear glass does not always result. In this case the crystalline phases and the glassy phase probably would differ in composition. The remelting of the sample may not then result in a uniform glass. (3) The possibility of the simultaneous existence of more than one liquid phase may not be completely ruled out. In one or two instances there

was some indication that two liquid phases were present.

The general trends noted in the previous papers^{1, 2} continue to be apparent in the compositional regions covered by data presented in Tables I, II, and III and pictured graphically in Figs. 1, 2, and 3.

In Fig. 1 (*B*) and (*C*) the isokoms exhibit more curvature than is common in other regions of composition. The authors doubt the reality of this. The isokoms are fairly straight at 1500°C., but become curved at the two lower temperatures. This whole region is one in which the isotherms, although unknown except along the zero per cent MgO edge of the triangular diagrams, are probably quite close.

The patterns of the isokoms in Figs. 2 and 3 are logical if one reasons from the earlier data.^{1, 2} They require no comment.

TABLE II.—VISCOSITY DATA FOR THE SYSTEM
LIME—MAGNESIA—ALUMINA—SILICA ($\text{SiO}_2=45\%$)

| Melt No. | Composition (Wt. %) | | | Viscosity (poises) (°C.) | | | | | |
|-------------|-------------------------|-----|-----|-----------------------------|------|------|------|------|------|
| | Al_2O_3 | CaO | MgO | 1500 | 1450 | 1400 | 1350 | 1300 | 1250 |
| 54 | 0 | 55 | 0 | 2.33 | | | | | |
| 55 | 0 | 50 | 5 | 2.25 | 3.08 | 4.46 | | | |
| 56 | 0 | 45 | 10 | 2.24 | 3.07 | 4.45 | | | |
| 57 | 0 | 40 | 15 | 2.10 | 2.89 | 4.11 | | | |
| 58 | 0 | 35 | 20 | 2.11 | 2.84 | 3.96 | | | |
| 59 | 0 | 30 | 25 | 1.94 | | | | | |
| 60 | 5 | 50 | 0 | 3.41 | 4.80 | | | | |
| 61 | 5 | 45 | 5 | 3.81 | 4.91 | 7.47 | | | |
| 62 | 5 | 40 | 10 | 2.99 | 4.19 | 6.56 | 10.3 | | |
| 63 | 5 | 35 | 15 | 2.84 | 3.98 | 5.68 | 9.03 | | |
| 64 | 5 | 30 | 20 | 2.79 | 3.80 | 5.92 | | | |
| 65 | 5 | 25 | 25 | 2.46 | | | | | |
| 67 | 10 | 45 | 0 | 5.08 | 7.57 | 11.6 | | | |
| 68 | 10 | 40 | 5 | 4.79 | 6.97 | 10.6 | 16.9 | 29.6 | 57.9 |
| 69 | 10 | 35 | 10 | 4.58 | 6.90 | 10.2 | 16.0 | 27.5 | |
| 70 | 10 | 30 | 15 | 4.07 | 5.92 | 8.79 | 13.4 | 23.0 | 45.7 |
| 71 | 10 | 25 | 20 | 3.90 | 5.40 | 8.40 | | | |
| 72 | 10 | 20 | 25 | 3.67 | | | | | |
| 73 | 15 | 40 | 0 | 8.54 | 12.6 | 19.4 | 33.1 | | |
| 74 | 15 | 35 | 5 | 7.60 | 11.1 | 17.3 | 28.8 | 50.8 | 102 |
| 75 | 15 | 30 | 10 | 6.76 | 9.80 | 15.1 | 24.3 | 42.4 | 82.1 |
| 76 | 15 | 25 | 15 | 6.68 | 9.45 | 14.4 | 23.3 | 41.1 | |
| 77 | 15 | 20 | 20 | 5.97 | 8.19 | 12.2 | | | |
| 78 | 15 | 15 | 25 | 5.01 | | | | | |
| 79 | 20 | 35 | 0 | 15.0 | 22.6 | 37.2 | 63.3 | 125 | 272 |
| 80 | 20 | 30 | 5 | 15.7 | 20.5 | 31.4 | 52.7 | 100 | 212 |
| 81 | 20 | 25 | 10 | 13.3 | 17.2 | 26.3 | 43.1 | 80.7 | 169 |
| 83A | 20 | 20 | 15 | 9.71 | 14.2 | 21.8 | 36.0 | 66.9 | |
| 84 | 20 | 15 | 20 | 8.41 | 12.5 | 19.1 | 32.2 | | |
| 85 | 20 | 10 | 25 | 7.72 | 11.4 | | | | |
| 90 | 25 | 30 | 0 | 26.3 | 41.0 | 70.0 | 132 | | |
| 91 | 25 | 25 | 5 | 22.3 | 37.9 | 57.2 | 106 | | |
| 92 | 25 | 20 | 10 | 20.2 | 30.2 | 41.8 | 76.0 | 152 | |
| 93A | 25 | 15 | 15 | 14.4 | 22.3 | 36.4 | 61.8 | 126 | |
| 94 | 25 | 10 | 20 | 12.9 | 20.0 | 31.7 | 51.7 | 105 | |
| 95 | 25 | 5 | 25 | 10.6 | 17.0 | 30.6 | | | |
| 96 | 30 | 25 | 0 | 70.5 | | | | | |
| 97 | 30 | 20 | 5 | 45.8 | 75.6 | | | | |

TABLE III.—VISCOSITY DATA FOR THE SYSTEM
LIME-MAGNESIA-ALUMINA-SILICA (SILICA = 50%)

| Melt No. | Composition (Wt. %) | | | Viscosity (poises) (°C.) | | | | | |
|-------------|--------------------------------|-----|-----|-----------------------------|------|------|------|------|------|
| | Al ₂ O ₃ | CaO | MgO | 1500 | 1450 | 1400 | 1350 | 1300 | 1250 |
| 149 | 0 | 45 | 5 | 3.08 | | | | | |
| 150 | 0 | 40 | 10 | 2.86 | 3.90 | 5.71 | | | |
| 151 | 0 | 35 | 15 | 2.68 | 3.74 | 5.39 | 8.29 | | |
| 152 | 0 | 30 | 20 | 2.61 | 3.56 | 5.10 | 7.68 | | |
| 153 | 0 | 25 | 25 | 2.80 | 3.76 | | | | |
| 131 | 5 | 45 | 0 | 4.78 | | | | | |
| 175 | 5 | 40 | 5 | 4.76 | 6.52 | 9.70 | | | |
| 176 | 5 | 35 | 10 | 4.40 | 6.08 | 9.07 | 14.2 | 23.8 | |
| 177 | 5 | 30 | 15 | 4.15 | 5.60 | 8.19 | 12.6 | 20.5 | |
| 178 | 5 | 25 | 20 | 3.93 | 5.53 | 8.08 | 12.1 | 23.6 | |
| 179 | 5 | 20 | 25 | 3.79 | 5.22 | | | | |
| 126 | 10 | 40 | 0 | 8.23 | 12.1 | 19.2 | | | |
| 186 | 10 | 35 | 5 | 7.53 | 10.9 | 16.9 | 27.1 | 46.2 | 89.9 |
| 185 | 10 | 30 | 10 | 7.09 | 9.92 | 15.0 | 23.8 | 39.1 | 75.0 |
| 184 | 10 | 25 | 15 | 6.71 | 8.90 | 13.1 | 20.9 | 33.8 | 67.2 |
| 183 | 10 | 20 | 20 | 5.88 | 8.12 | 12.2 | 19.5 | | |
| 182 | 10 | 15 | 25 | 5.49 | 7.97 | | | | |
| 121 | 15 | 35 | 0 | 14.3 | 21.9 | 34.8 | 57.1 | 105 | 209 |
| 194 | 15 | 30 | 5 | 15.2 | 20.4 | 31.5 | 49.6 | 92.2 | 183 |
| 193 | 15 | 25 | 10 | 12.8 | 18.6 | 27.9 | 43.8 | 80.3 | 160 |
| 192 | 15 | 20 | 15 | 10.9 | 16.2 | 24.3 | 37.8 | 69.4 | 137 |
| 191R | 15 | 15 | 20 | 9.51 | 13.7 | 21.4 | 35.0 | | |
| 190 | 15 | 10 | 25 | 8.20 | 12.6 | | | | |
| 189 | 15 | 5 | 30 | 8.61 | | | | | |
| 117 | 20 | 30 | 0 | 30.2 | 42.3 | 70.9 | 126 | 247 | 529 |
| 199 | 20 | 25 | 5 | 25.2 | 37.3 | 64.3 | 115 | 227 | 485 |
| 198R | 20 | 20 | 10 | 22.2 | 33.8 | 53.8 | 93.0 | 178 | 381 |
| 197R | 20 | 15 | 15 | 17.0 | 26.3 | 41.9 | 71.1 | 134 | 277 |
| 196 | 20 | 10 | 20 | 14.3 | 21.4 | 33.9 | 57.7 | 112 | |
| 195 | 20 | 5 | 25 | 13.2 | 20.3 | 33.0 | 52.7 | | |
| 140 | 25 | 25 | 0 | 57.7 | 99.8 | | | | |
| 203 | 25 | 20 | 5 | 41.6 | 69.4 | 121 | | | |
| 202 | 25 | 15 | 10 | 34.1 | 53.3 | 93.0 | 172 | 396 | |
| 201 | 25 | 10 | 15 | 26.6 | 40.6 | 71.2 | 132 | 265 | 591 |
| 200 | 25 | 5 | 20 | 21.0 | 33.3 | 54.9 | 102 | 202 | |

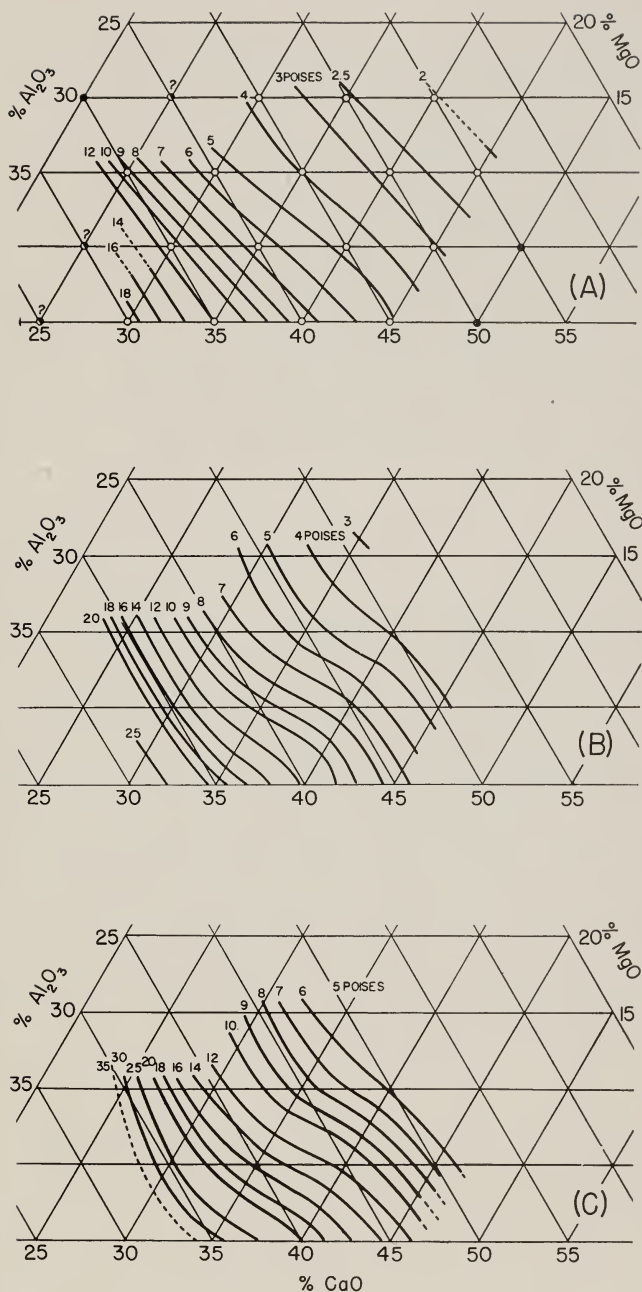


FIG. 1.—(A) Isokoms, 1500° C. (35% SiO₂). Solid circles indicate experimental compositions not molten at 1500° C.; hollow circles indicate experimental compositions molten at 1500° C. or lower. (B) Isokoms, 1450° C. (35% SiO₂). (C) Isokoms, 1400° C. (35% SiO₂).

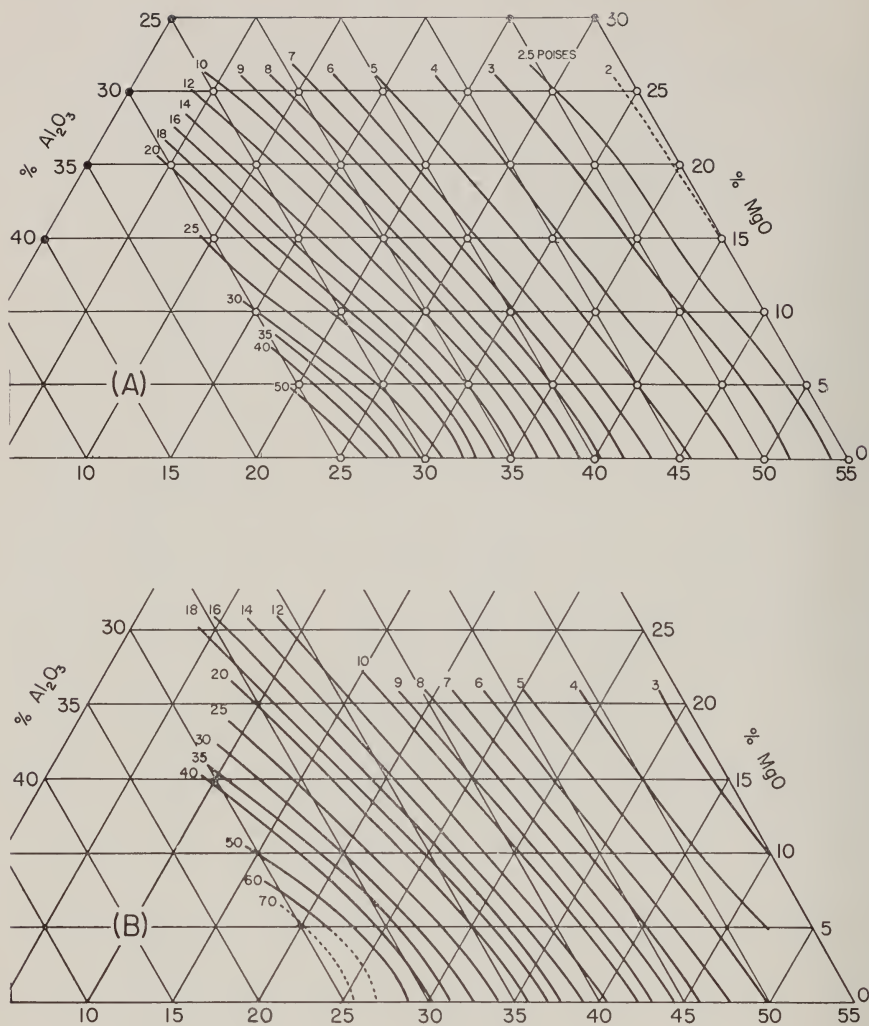


FIG. 2.—(A) Isokoms, 1500° C. (45% SiO_2). Solid circles indicate experimental compositions not molten at 1500° C.; hollow circles indicate experimental compositions molten at 1500° C. or lower. (B) Isokoms, 1450° C. (45% SiO_2). (C) Isokoms, 1400° C. (45% SiO_2). (D) Isokoms, 1350° C. (45% SiO_2).

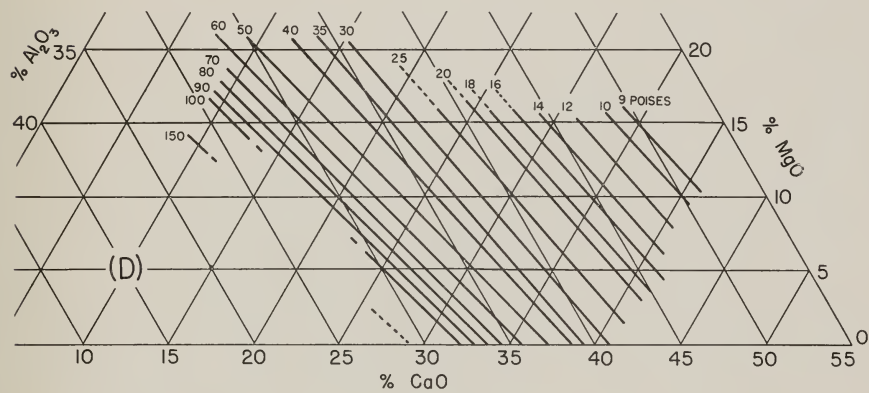


FIG. 2—Continued.

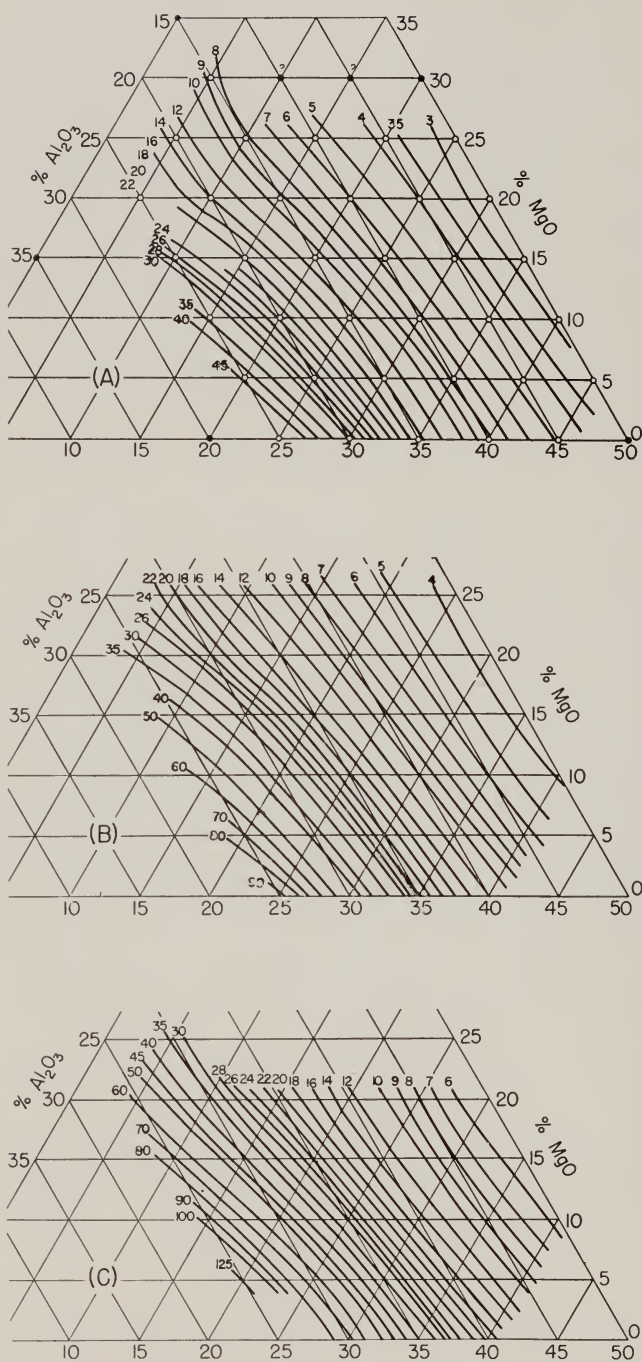


FIG. 3.—(A) Isokoms, 1500° C. (50% SiO₂). Solid circles indicate experimental compositions not molten at 1500° C.; hollow circles indicate experimental compositions molten at 1500° C. or lower. (B) Isokoms, 1450° C. (50% SiO₂). (C) Isokoms, 1400° C. (50% SiO₂). (D) Isokoms, 1350° C. (50% SiO₂).

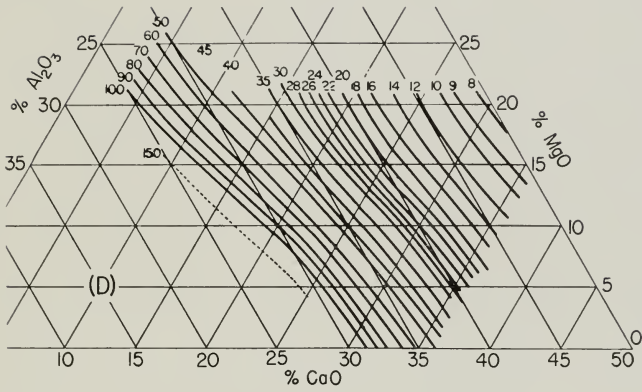


FIG. 3—Continued.

